The Extratropical Transition of Tropical Cyclones

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LONG-TERM GOALS

To improve tropical cyclone structure and intensity prediction through a research program combining high-resolution modeling and detailed observational studies to investigate physical processes by which the structure and intensity of a tropical cyclone are modified.

OBJECTIVES

The objective is to investigate the physical processes that occur as a tropical cyclone interacts with the environment such that intensity and structure changes occur. Specific interactions being studied are with baroclinic environments in the midlatitudes during extratropical transition. During extratropical transition, radical changes to the storm structure occur as vertical wind shear and intruding cold, dry air from the midlatitudes erode the warm core. Re-intensification to a strong midlatitude system is possible. In cases in which forecast models poorly predicted the motion and re-intensification of the storm during these transitional periods, better understanding of these processes should improve motion and intensity forecasts.

APPROACH

Three approaches are being used in this study. First, due to the scarcity of detailed observations in regions where tropical cyclones develop and move, high-resolution, idealized modeling is combined with observations to study the detailed structural changes that occur as a tropical cyclone interacts with the midlatitudes. The degree of physical complexity included in current mesoscale models allows detailed examination of environmental and small-scale impacts on the motion, structure, and intensity of tropical cyclones. However, caution must be taken when applying cause and effect arguments to describe the complex physical interactions that develop in these high-resolution models since they may be a product of the model parameterizations rather than realistic physical processes. Thus, a tiered approach is employed in which understanding of basic processes comes first and is built upon by gradually adding to the complexity of the modeling system, while isolating each physical process in turn. The U.S. Navy's coupled ocean-atmosphere mesoscale prediction system (COAMPS) is the primary model used in these studies into extratropical transition effects on tropical cyclone intensity and structure. Where available, detailed observations such as those available from the ONR-sponsored TCM-92 and TCM-93 field experiments are used to verify processes examined in the model experiments.

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14. ABSTRACT
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The extratropical transition of tropical cyclones has been shown to be very sensitive to both the structure of the midlatitude environment and the phasing between the tropical cyclone and midlatitude, upper-level trough. Forecast models have shown significant sensitivity from forecast to forecast depending on how this interaction is handled in the model. Thus, the second approach studies the sensitivity of the interaction between the midlatitude environment and tropical cyclone by varying the both the structure of the midlatitude environment and the phasing between the midlatitude trough and the tropical cyclone. This approach is highly dependent on the versatility of the modeling system employed, where many simple changes to the initial conditions of the model are made to cover a phase space of variability of the relative positions and strengths of the midlatitude environment and tropical cyclone.

The third approach uses a statistical methodology to develop a forecast technique for extratropical transition. The idea is to objectively determine ahead of time which systems will dissipate during ET and which will intensify, when this will happen, and by how much. Initially a single-variate, static approach using the 500-mb geopotential height analyses produced twice-daily by the Navy's Operational Global Assimilation and Prediction System (NOGAPS) has been developed. Pattern recognition techniques are employed to develop a prediction threshold that will allow a good success rate of prediction with an acceptable false alarm rate. The technique is being extended to include spatio-temporal and multi-variate analysis incorporating remotely-sensed data prediction.

WORK COMPLETED

Thirty-two simulations using COAMPS investigated how the phasing between the tropical cyclone and upper-level trough impacted the final intensification/dissipation of the extratropical cyclone. Previous work was extended to alter the initial location of the tropical cyclone relative to the upper-level trough, and the cases were then integrated out for 192 hours until either reintensification had completed or the system had advected out of the domain of interest. The results are being reported at several conferences (Ritchie 2005, Gaudet and Ritchie 2005, Ritchie and Elsberry 2005a) and a journal article (Ritchie and Elsberry 2005b) from this study has been submitted to Monthly Weather Review.

Simulations using COAMPS investigating the sensitivity of these results to the initial strength of the upper-level trough are currently being run and studied. The trough structure used is the moderate-strength trough reported in Ritchie and Elsberry (2003). Results show that a similar spatial pattern of intensification/decay exists for increasing strength of the upper-level trough, but this spatial pattern is offset slightly, i.e., as the strength of the trough increases, the final intensity achieved during reintensification increases for a particular relative initial location of the TC and trough.

A predictive technique has been developed to forecast the intensification or dissipation of a system during ET. For the purposes of the technique, ET is defined as the first time the TC appears as an open wave in the NOGAPS 500-mb geopotential height analyses and it is after this time that either reintensification as an extratropical cyclone or dissipation will occur. The technique is currently restricted to the following parameters: 1) only discrete 500 mb height data are considered; and 2) only a positive (reintensification) or negative (dissipation) outcome is considered. Predictions for ET cases in the western North Pacific in 2003 and 2004 have been made.

RESULTS

The extratropical transition of tropical cyclones can be associated with the rapid development of high winds, intense precipitation, and heavy seas, making these transitioned cyclones a significant forecast problem for shipping. Of particular interest is the potential for intensification in some systems when, as part of an interaction with an upper-level trough, re-deepening of the tropical cyclone remnants to a significant midlatitude storm takes place. The sensitivity of the ensuing interaction between the TC and midlatitude upper-level trough is explored in a series of high-resolution simulations using the NAVY's mesoscale model (COAMPS – Hodur 1997). Results from Ritchie and Elsberry (2003), which explored the interaction of a tropical cyclone with an upper-level trough of varying strength, are extended by locating the tropical cyclone in different initial positions relative to the weak trough.

A clear pattern of dissipation/re-intensification emerges that corresponds to the spatial patterning of the initial TC locations relative to the upper-level trough. In figure 1, the names corresponding to each case refers to the relative location of the TC to the trough, i.e., 15S15E means that the TC was initially located 15 degrees S and 15 degrees E of the upper-level trough.

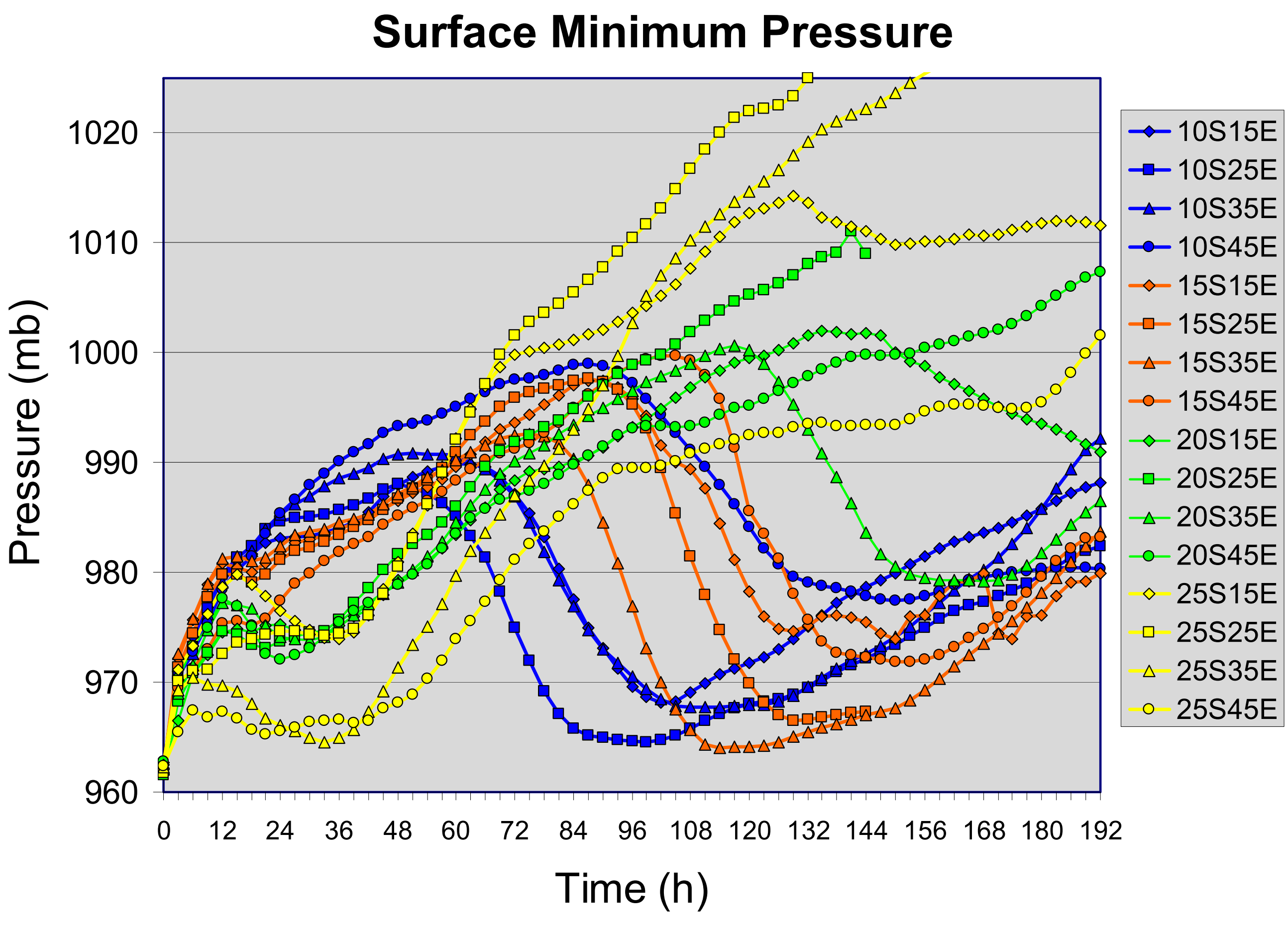

Fig. 1. Time series of the minimum surface pressure for each of the sixteen simulations of a tropical cyclone interacting with an upper-level trough.

A pattern emerges in the minimum sea-level pressure traces with four main sets: dissipators, weak intensifiers, moderate intensifiers (1 case), and strong intensifiers. In this set of simulations it is clear that the final intensity of the extratropical cyclone is related to its initial position relative to the upper-level trough, and this is because this position relates to how well the TC phases with the upper-level trough. Based on these simulations, an important conclusion is that there is a relationship between the relative location of the TC to the trough *ahead of time* and how it will intensify during the transition. Time series of physical parameters have been developed using these simulations that distinguish between intensifying and dissipating cases of ET *ahead of time* (Ritchie and Elsberry 2005b). These parameters include midlevel positive vorticity advection and precipitation in the northern sector of the tropical cyclone, upper-level divergence in the inner (within 600 km of the TC center) northwest quadrant, and low-level temperature advection in all inner quadrants. Additional work is being done to determine whether a combination of these parameters into an "ET parameter" will provide predictive information when applied to NWP analyses rather than COAMPS simulations.

An additional set of sixteen simulations have been run using the same spatial patterning of initial locations, but with a moderate-strength trough (Ritchie and Elsberry 2003). When compared to the weak trough set of simulations it is clear that the ultimate intensity of the extratropical system is primarily linked to initial location (i.e., phasing) of the tropical cyclone relative to the trough, and secondarily to the strength of the midlatitude circulation. A representation of the initial locations of the TCs with final intensities for both sets of simulations is presented in figure 2.

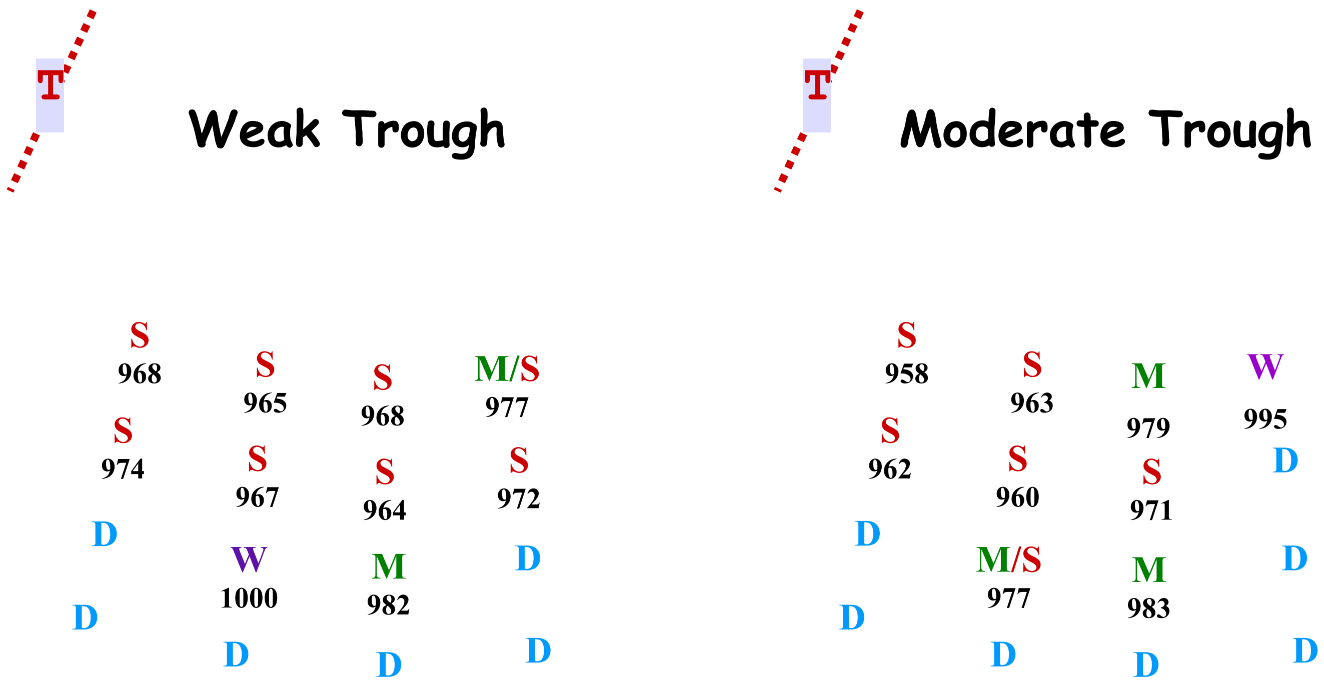

Fig. 2. Outcomes for each of the sixteen simulations based on whether a weak or moderate trough was present. S = strong, M = moderate, W = weak, and D = dissipater.

The forecasting of extratropical transition is a particularly difficult problem, in part because the tropical cyclone is rapidly accelerating as it moves into the midlatitudes. An objective technique is being developed to determine ahead of time whether a particular tropical cyclone will reintensify or dissipate during transition. The techniques uses pattern recognition and signal processing techniques to identify cases that will intensify (positive cases) versus those that will not (negative cases). Figure 3 shows results from a test of 2004 transitioning cases in the western North Pacific. Cases highlighted in grey are negative (dissipating cases). At 24 hours prior to ET, (ET is the decision time after which either reintensification or dissipation will occur), a probability of detection of 63% with a false alarm rate of 0% is achieved. This is the best result achieved so far and shows that the technique has predictive value at least 24 hours prior to when a decision must be made. We are investigating why prediction seems to decrease after ET-24 hours. In addition, we are currently exploring ways to make the system truly spatiotemporal as well as methods to add other types of data that discriminate between the two types of systems into the technique. As our technique improves we will add the capability of predicting amounts and time of reintensification.

2004 Storms tested on previous history of {97,....,03}

		ET-48h				ET-36h				ET-24h				ET-12h			
2004	1	1	0	0	0	1	0	0	0	1	1	1	1	0	0	0	0
	2	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
	3	1	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0
	4	0	0	0	0	0	0	1	1	0	1	1	1	0	0	0	1
	5	1	1	1	1	0	1	1	1	1	1	1	1	0	0	0	0
	6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	7	0	0	0	0	0	1	1	1	0	1	1	1	0	0	1	1
	8	1	1	1	1	1	1	1	1	0	1	1	1	0	1	1	1
	9	0	0	0	0	0	0	0	1	0	0	0	0	1	1	1	1
	10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
	12	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0
	13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	14	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0
	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	all %	60	47	47	47	60	67	73	87	60	80	80	87	40	40	40	47
	PD %	25	25	25	25	25	50	63	88	25	63	63	75	13	25	38	50
	PFA %	0	29	29	29	0	14	14	14	0	0	0	0	29	43	57	57

		ET+00h				ET+12h				ET+24h				ET+36h				ET+48h			
2004	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
	3	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0
	4	0	0	1	1	1	1	1	1	0	1	1	1	1	1	1	1	0	1	1	1
	5	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
	7	0	0	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	8	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	10	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
	11	1	1	0	0	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1
	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
	13	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	14	1	1	1	1	0	0	1	1	1	1	1	1	0	1	1	1	1	1	1	1
	15	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	all %	40	47	60	67	67	60	73	67	67	73	67	67	67	73	73	73	80	87	80	73
	PD %	25	38	75	88	50	50	75	75	63	75	75	75	63	75	75	75	75	88	88	88
	PFA %	43	43	57	57	14	29	29	43	29	29	43	43	29	29	29	29	14	14	29	43

Fig. 3. A truth-false table for prediction of the ET of 2004 storms in the western North Pacific basin. The grey highlight indicates the negative cases. A "1" indicates a correct prediction and a "0" indicates an incorrect prediction.

SUMMARY

Significant advances have been made in the understanding of how a tropical cyclone interacts with the surrounding environment. Because interaction with the environment affects a tropical cyclone's intensity and structure, it is important to understand these processes in order to predict intensity change of a tropical cyclone. The intensity changes associated with extratropical transition of a tropical cyclone are particularly difficult to forecast and the knowledge we gain in studying the physical processes associated with the movement of a tropical cyclone to higher latitudes can help to improve forecasts of these phenomena. Because it is very difficult to get high spatial- and temporal-resolution data sets of extratropical transition, the use of carefully constructed high-resolution simulations is one of our best ways of improving our understanding of the physical processes associated with extratropical transition of tropical cyclones. The work described here will be continued in order to advance this knowledge.

New satellite technology has provided an abundance of data sources to forecasters, particularly in the remote tropical oceans where data have been traditionally sparse. These data can be difficult to process in the forecast office where timely forecasts must be provided every few hours. We are developing an objective forecast technique that makes use of this data to aid in the forecasting of the extratropical transition of tropical cyclones.

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